Joint NRC/EPRI xLPR Probabilistic Fracture Mechanics Code: Pilot Study Results

Introduction

General Design Criterion 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," requires that primary piping systems exhibit an extremely low probability of rupture in order to exclude dynamic effects associated with postulated pipe ruptures from the design basis.

The deterministic leak-before-break (LBB) methodology, as described in the U.S. Nuclear Regulatory Commission's (NRC's) Standard Review Plan (NUREG-0800 or SRP) Section 3.6.3, was developed to meet this goal. In recent years, probabilistic analysis has matured to provide the flexibility to evaluate a wide variety of materials, degradation mechanisms, application of mitigation techniques, and the influence of inspection.

Therefore, the NRC has initiated the development of a probabilistic assessment tool (xLPR) as an alternative to the deterministic evaluation criteria of the SRP.

This poster provides an overview of the xLPR program, focusing on the collaborative structure used for model development and the current proof-of-concept pilot study.

Motivation

Systems approved for LBB have experienced degradation mechanisms such as stress-corrosion cracking. The SRP was developed before the advent of this operating experience. xLPR will provide a probabilistic framework to address degradation mechanisms.

In addition to modeling degradation mechanisms, xLPR models mitigation strategies (such as weld overlays) and the influence of inspection technology on pipe failure frequency.

Objectives of NRC/EPRI-Sponsored Research

Develop a robust methodology for evaluating reactor coolant system piping rupture probabilities.

Select appropriate, technically sound input data and models to produce best-estimate output results with quantified uncertainty.

Develop a computational software tool that applies the input data and models and appropriately treats epistemic and aleatory uncertainties.

Verify, validate, benchmark, and document the software tool to enable its use in support of design and regulatory decisions by both industry and the NRC.

Cooperative Research

The NRC and the Electric Power Research Institute (EPRI) signed a memorandum of understanding (MOU) to allow and encourage cooperation in nuclear safety research that benefits both the NRC and industry.

The MOU is authorized under Section 31 of the Atomic Energy Act and Section 205 of the Energy Reorganization Act.

The xLPR project is being conducted under an addendum to the MOU to allow the NRC and EPRI to cooperatively conduct research on this project.

Nozzle geometry for xLPR pilot study

Current Research Efforts—xLPR Pilot Study

Demonstrate the feasibility of the proposed NRC-industry cooperative process and the probabilistic framework.

Develop an initial assessment tool specific to dissimilar metal pressurizer surge nozzle welds, accounting for weld residual stresses and primary water stress-corrosion cracking.

Conduct a probabilistic assessment of surge nozzle dissimilar metal weld leakage and rupture.

Develop order-of-magnitude estimate calculations of piping rupture probabilities and identify areas requiring more focused attention in the long-term study.

Pilot Study Code, xLPR Version 1.0

- Two probabilistic computational frameworks (open source and commercial) considered
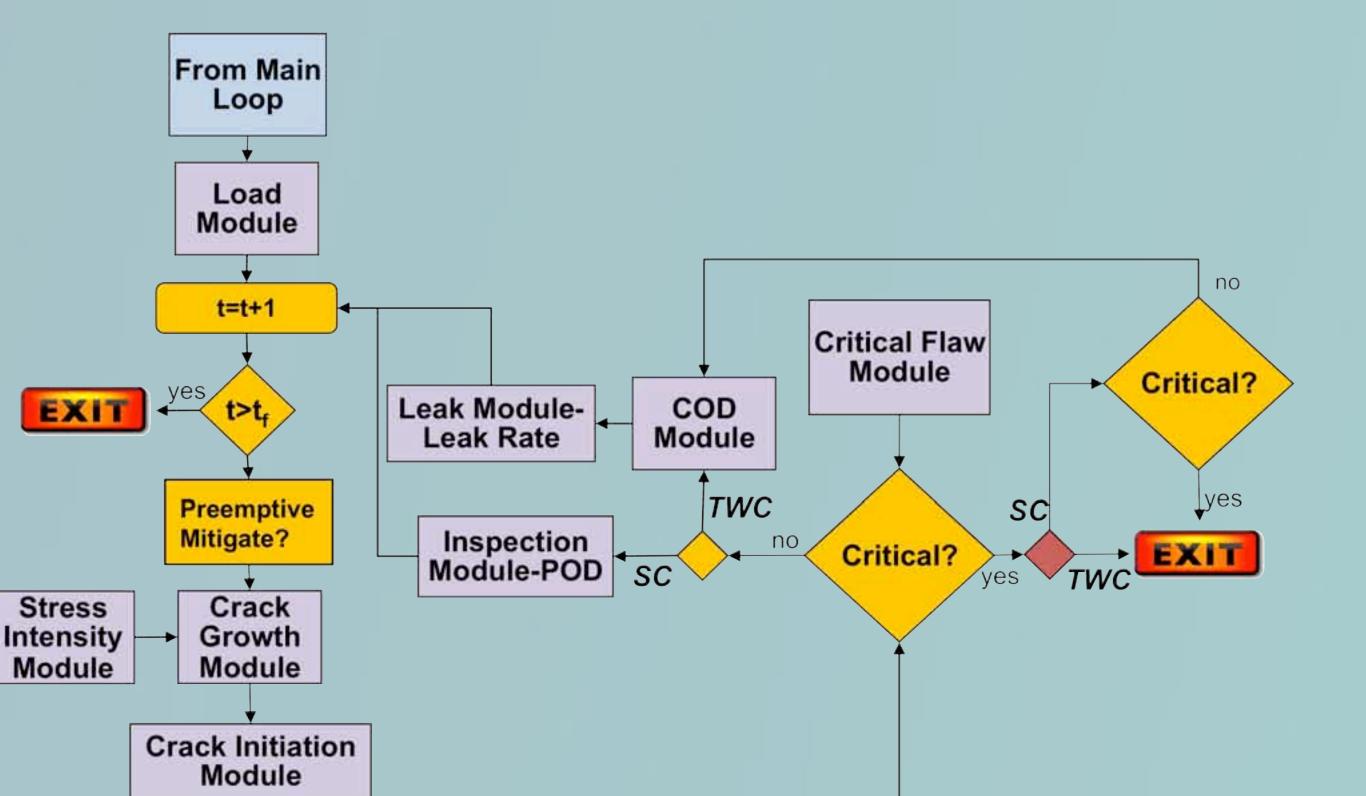- Modularized for maximum flexibility
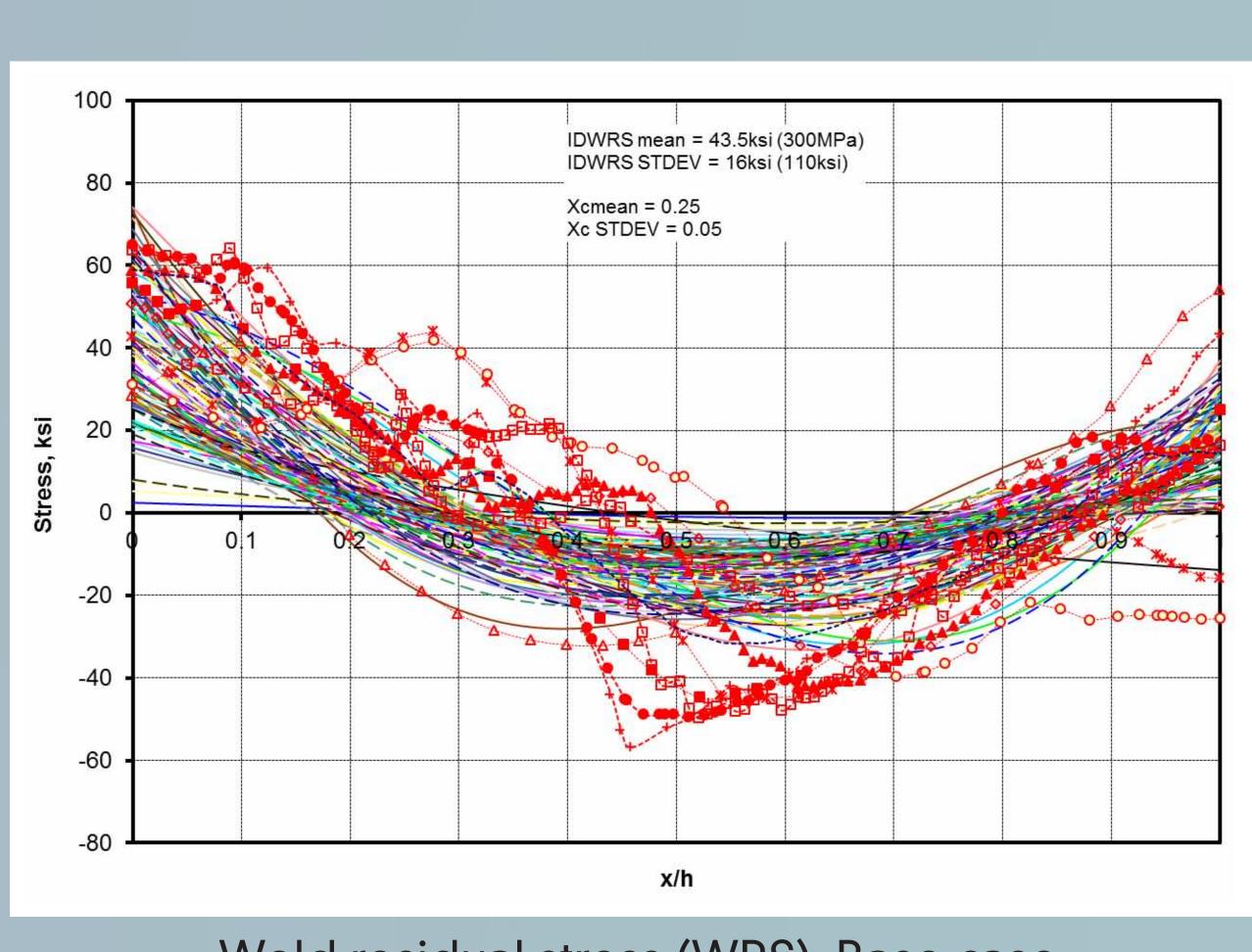- Written and verified through the configuration management process

xLPR Version 1.0 commercial framework (left) and open-source framework (right)

xLPR Version 1.0 Time Loop Flow Chart, with modules in purple
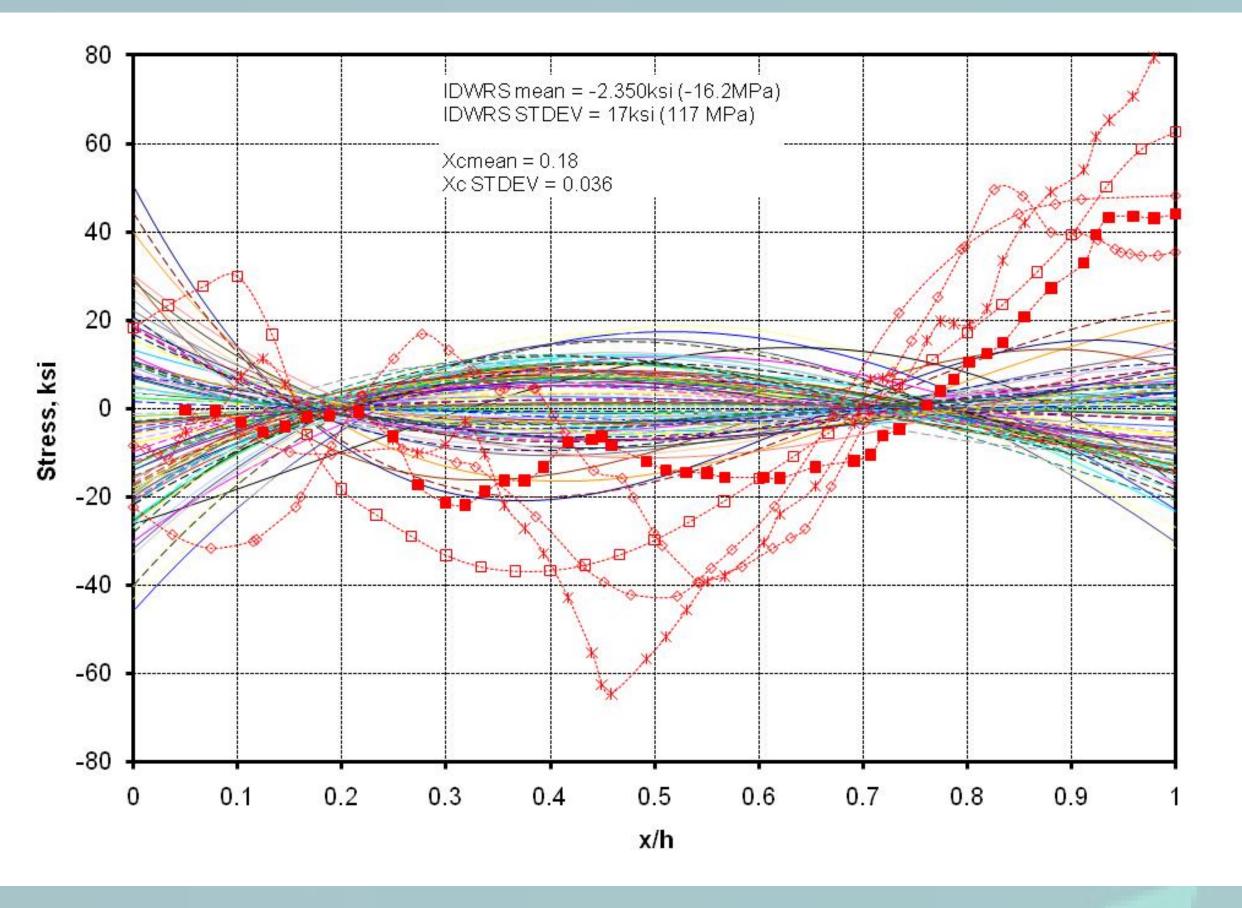
Pilot Study Problem

Base case—higher WRS with no inspection, mitigation, or leak detection (High WRS not representative for typical surge nozzle —meant to demonstrate feasibility)
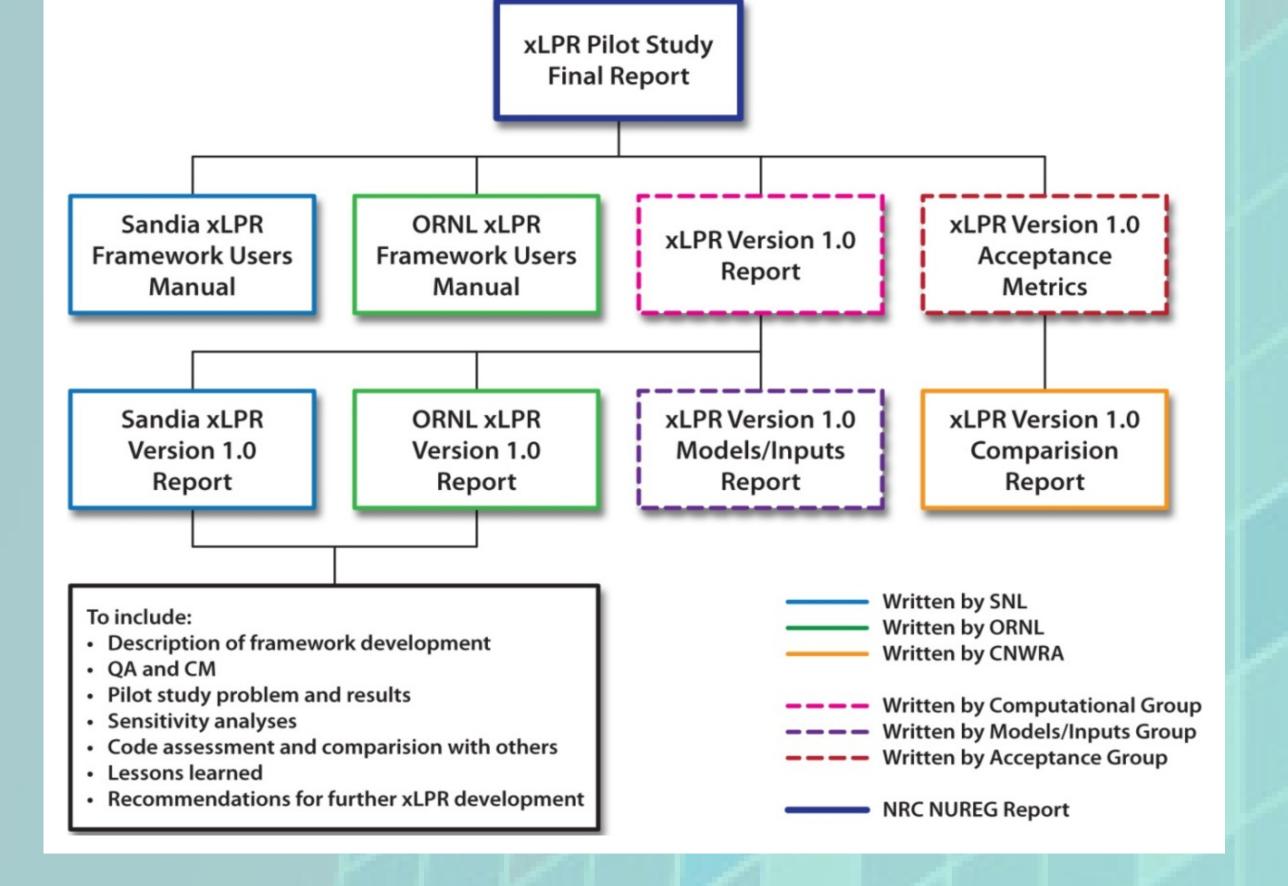
Sensitivity studies
- WRS—with safe-end weld
- Mitigation at 10, 20, and 40 years
- Different crack initiation model
- Adding hydrogen—50cc/kg-STP, 80cc/kg-STP

Weld residual stress (WRS)–Base case

Safe end weld residual stress–Sensitivity case

xLPR Timeline

Pilot study completed 1st quarter fiscal year (FY) 2011

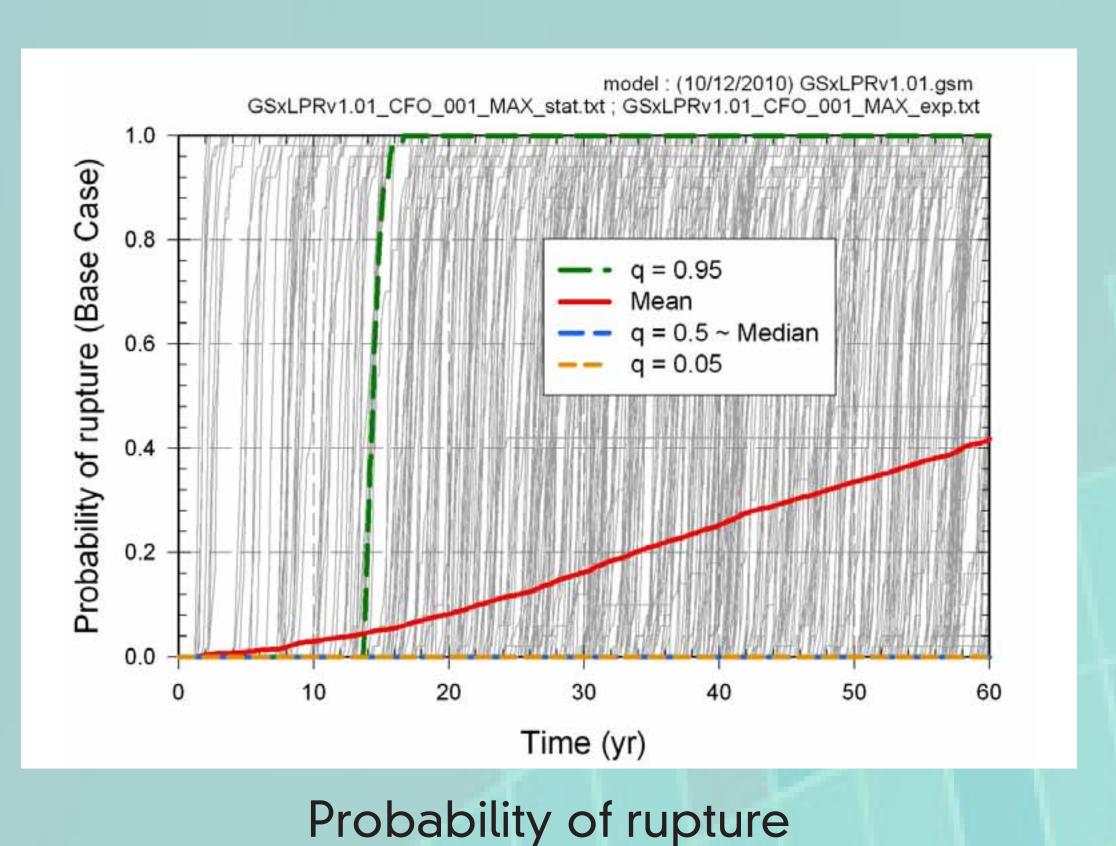Pilot study reports published 2nd and 3rd quarter FY 2011

Pilot Study Reports

xLPR Version 2.0 complete—2013

Modular code complete—2016

Version 1.0 Code—Pilot Study Results

Base case—Higher WRS with no inspection, mitigation, or leak detection (High WRS not representative for typical surge nozzle–meant to demonstrate feasibility)

Probability of rupture

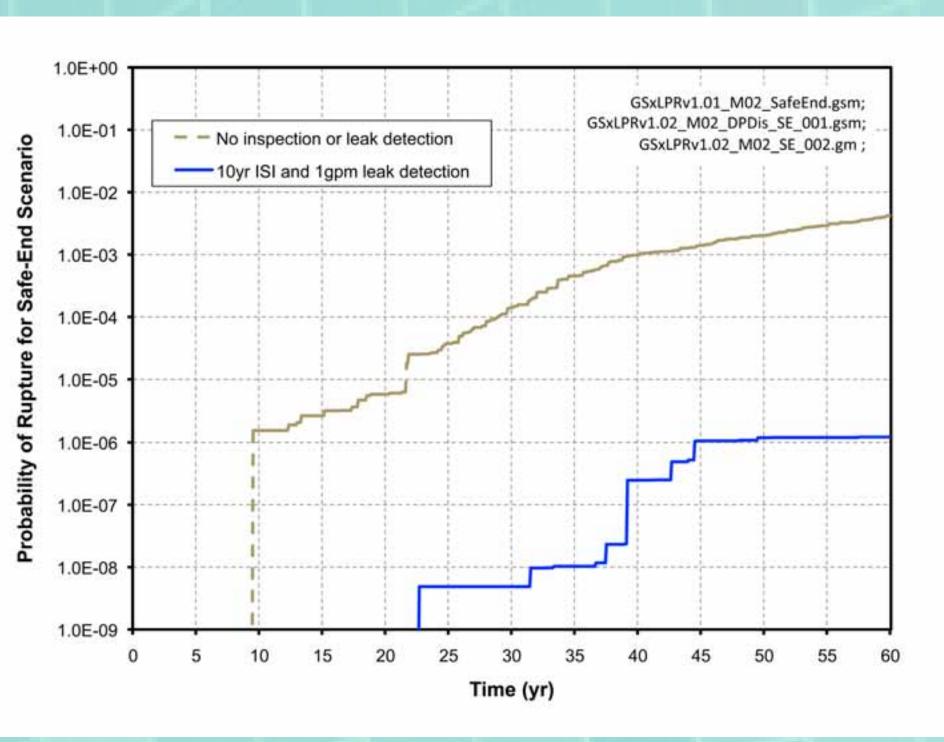Confidence in mean probability of rupture
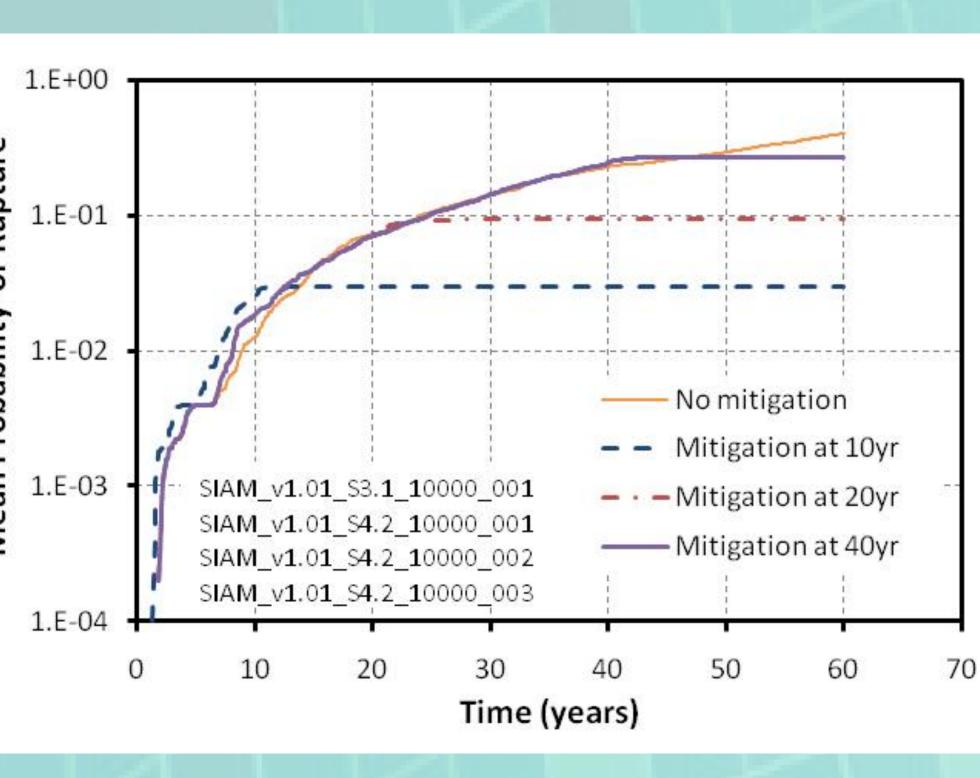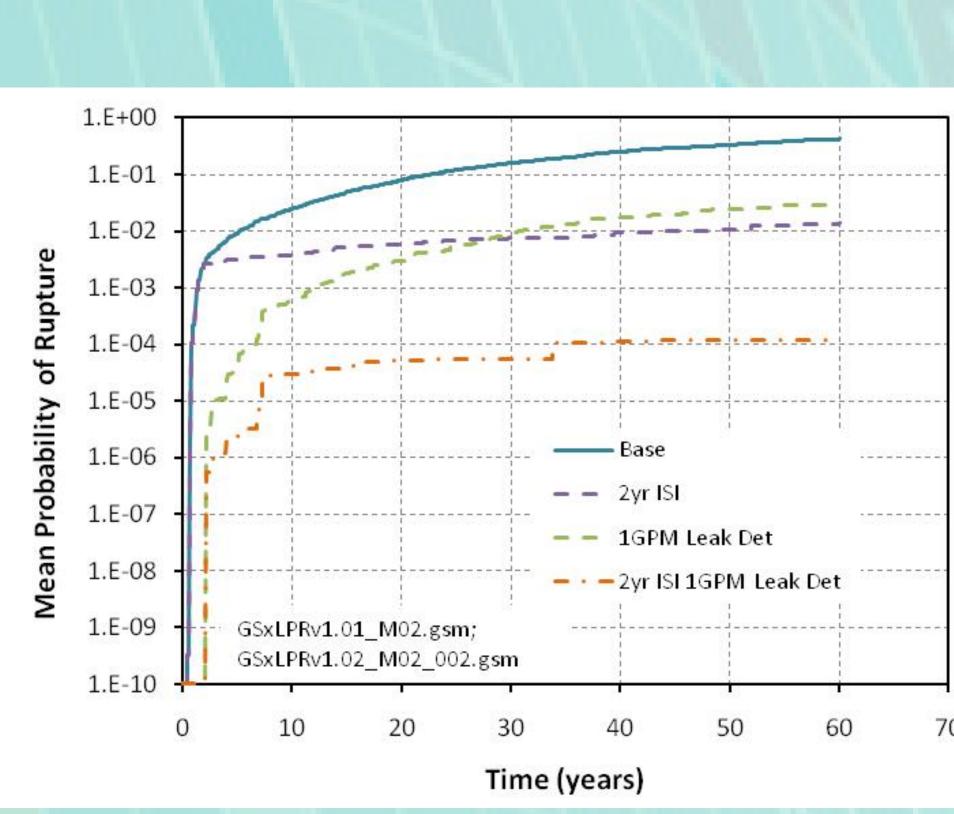
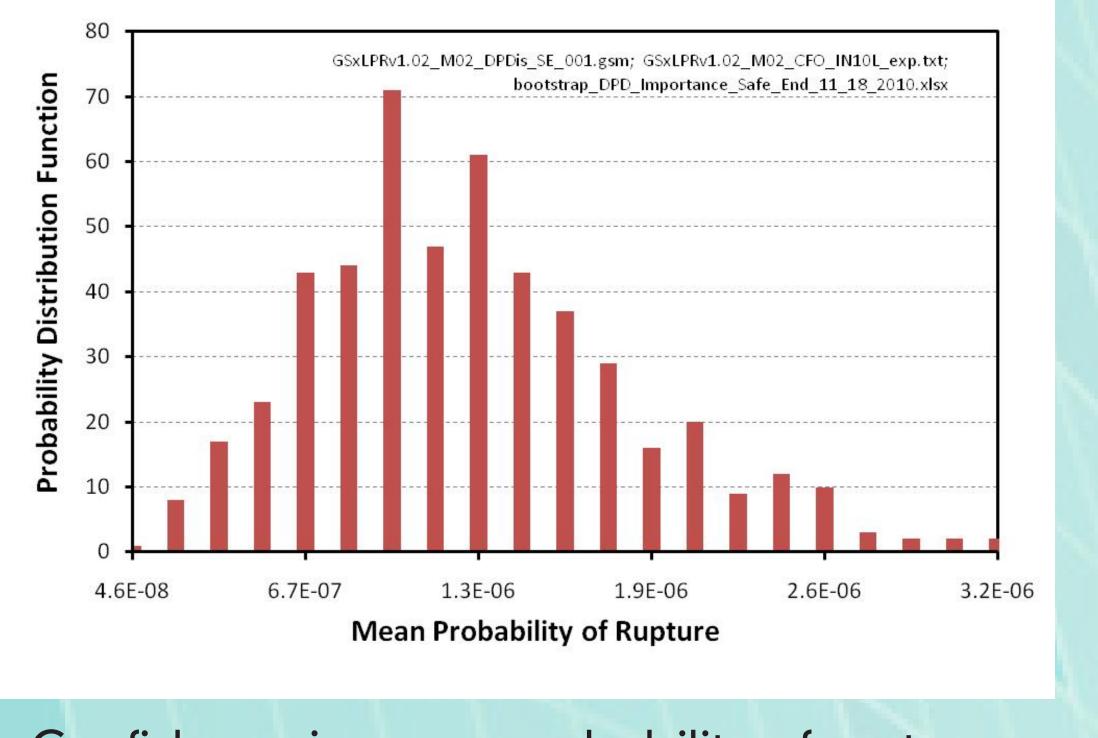Base case with preemptive mitigation

Base case with credit for inspection and leak detection

Sensitivity case—WRS with safe-end weld (WRS more representative for typical surge nozzle)

Mean probability of rupture

Confidence in mean probability of rupture